$^{40}Ar/^{39}Ar$ Ages of the Medford Diabase Dike
Boston and Boston Bay Area
Massachusetts

A thesis submitted to

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by

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Introduction

The Medford diabase dike is one of several intrusives in the Boston and Boston Bay areas of Massachusetts. Little is known of its relationships with the rest of the geology in the area and it has been considered Triassic in age. This age is based on a date of 190 m.y. obtained by one isotopic dating (Corrigan, 1972) and the ages of other intrusives in the area. The magnetic properties of the dike, both normal and reversed polarity, make this an important dike for study.

This project was initiated as part of the ongoing study of the Medford diabase dike and its possible relationship to the Central Atlantic rifting of the continental drift theory. The initiation of the Central Atlantic rift has been carried out by Dr. John F. Sutter, Timothy E. Smith, G. Brent Dalrymple, C. Sherman Gromme, and Richard W. White.

If fairly conclusive dates can be obtained for the dike, they will add to the accuracy of paleomagnetic reconstruction of the continents and provide a possible date for the Central Atlantic rift. It can also provide a date for the magnetic reversal and a positive contribution to the geologic history of the Boston and Boston Bay areas. In other words, it will help define the relationship of the dike to the rest of the geology in the Boston and Boston Bay areas.

Geologic Background

The Boston area is part of the geologic and geomorphic province that includes most of New England, southeast Quebec, and the Maritime provinces (LaForge, 1932). The Medford diabase is probably the largest and longest dike in the Boston area and is only one of several.

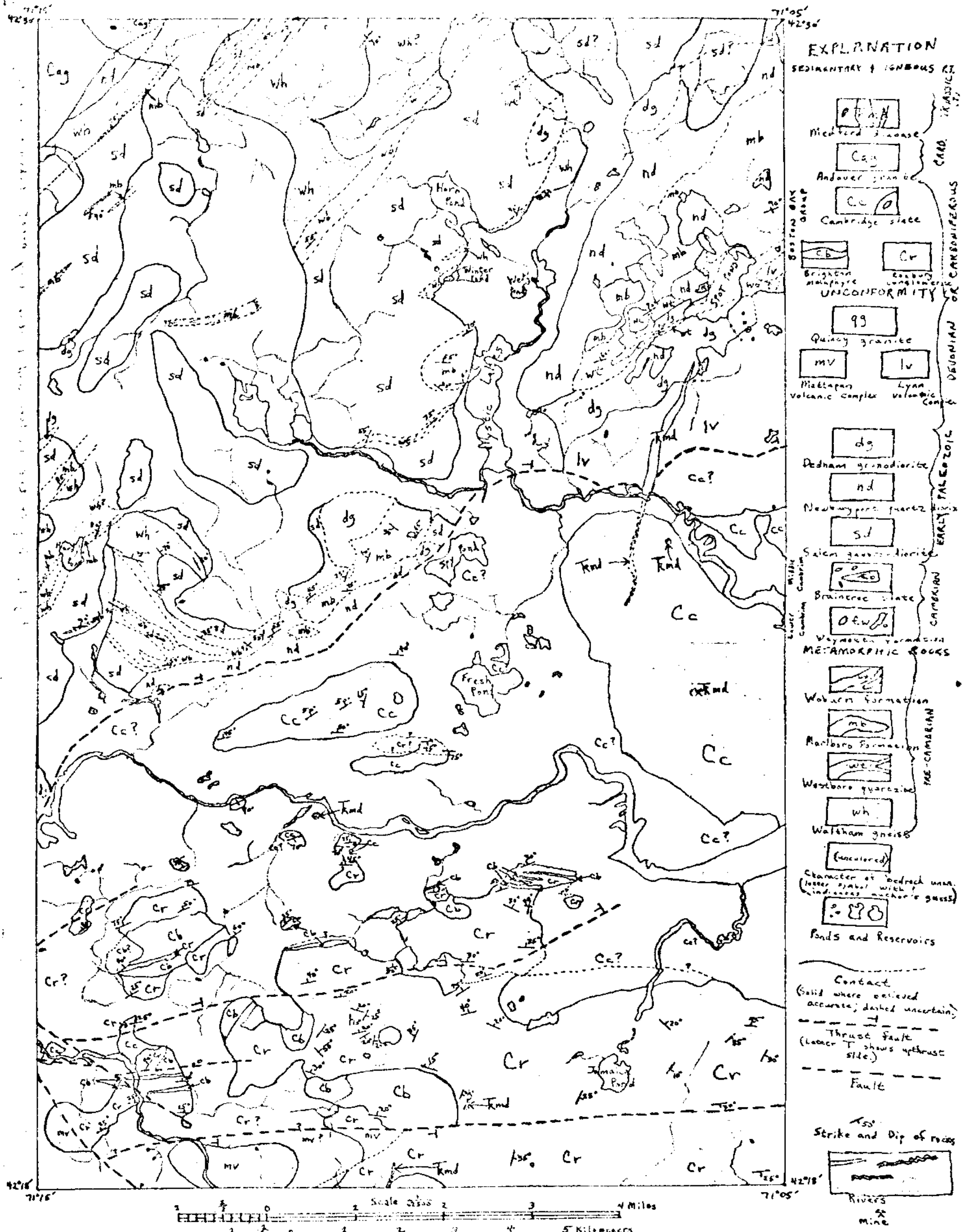
The dike has a strike trend of N19°E and an almost vertical dip. The northernmost and southernmost exposures are 11 miles apart. The main dike extends from Powderhouse Hill, in West Somerville, northward almost to Spot pond. The total distance is three miles and a maximum thickness of 560 feet is reached (LaForge, 1932). The approximate geographical coordinates of the known outcrop extremes are 42°23.9'N latitude, 71°06.3'W longitude (Corrigan, 1972).

The Medford intrudes the Cambridge slate of late Carboniferous age, the Roxbury conglomerate of early Carboniferous, the Lynn volcanic complex of Devonian (early) age, and the Dedham granodiorite of Early Paleozoic age. It also cuts the northern boundary fault zone, a thrust fault believed to have been generated in the late Carboniferous tectonic period. The dike is also younger than the younger east-west dikes of Late Paleozoic age. This seems to indicate that the Medford diabase dike has an age of Permian or younger (LaForge, 1932).

The numerous dikes in the Boston area were grouped into four sets, excluding the Medford, on the basis of trend. These four sets are:

1) The older east-west dikes that range from early to mid-Paleozoic in age;
2) The northwest-southeast dikes that range from middle to late Paleozoic in age;
3) The younger east-west dikes of late Paleozoic age;
4) The north-south dikes of late Triassic to early Jurassic age.

The trend of the Medford is similar to the north-south set, but it has lithologic and structural differences. The Medford dike is also cut by a north-south dike (LaForge, 1932). Therefore, in conjunction with the previous paragraph, one can assume an age that ranges from Permian to Late Triassic in age. These facts, which make the Medford diabase unique, have also led to the placing of the dike on a geologic map (see Fig. 1).



NORTH ARROW (assumed)
Magnetic Declination
(unknown since on original map)

Fig. 1: AREAL GEOLOGY OF THE BOSTON AND BOSTON BAY QUADRANGLES (MASSACHUSETTS)

BY

JOHN M. MCKINLEY, 1979 (after LaForge et al, 1932)

The $^{40}Ar/^{39}Ar$ Method and Analytical Techniques

Choice of Specimens

At first, specimens were chosen from the cores already in the possession of Dr. Sutter. After making thin sections of the two specimens (34 and 38) it was decided that they were insufficient for the dating that was to be carried out. Other specimens were then tried with no luck. Finally, Tim Smith, who did the Medford corings, was contacted and he sent a brochure on all the cores that he used. Dr. Sutter and I then decided to use 2 cores with normal magnetic data and 2 cores with reversed. Unfortunately, the normal polarity cores used in Tim Smith's original paleomagnetic calculations couldn't be found. It was finally decided to go with four cores that had reversed polarity and a good chance to be relatively unaltered. The cores finally chosen had the numbers 40B, 41B, 45, and 47.

Preparation for Irradiation

The first step in the preparation was to make thin sections of the four cores chosen in order to check out how much alteration had occurred. These thin sections will also be used for a petrographic study of the cores, which is to be used in the thesis. Two slides were made for each core. After thin sections were made, the remaining core material was crushed and pulverized to maximize the 60-100 size fraction. After sieving, my samples were so small, that I ended up using the 48/60, 60/80, and 80/100 size fractions. However, the greater than 48 and <100 were not used. A preliminary weighing of the final sample was then carried out and followed by washing of the samples in 10% HCL, tap water, acetone, alcohol, and distilled water (in that order). All four samples were then dried in the oven and placed in the dessicator. When the samples had dried, the samples were then transferred to aluminum capsules that were numbered carefully and weighed carefully. Each sample was placed in two aluminum capsules, numbers and weights were recorded, and each sample then was placed in a quartz vial separate from the others. The vials were then sealed and placed around a central core of ultrapure quartz in a "reactor vessel." This reactor vessel was then sent to Michigan for irradiation.

Dating of Samples and Reduction of Data

When the irradiation package was returned, dating procedures were carried out as soon as possible. Each sample was fused and gases were extracted and purified according to the method describe by Dalrymple and Lanphere (1969, pp. 62-65). In addition to this procedure, modifications for $^{40}Ar/^{39}Ar$ dating, also according to Dalrymple and Lanphere (1971, pp. 300-308; 1974, pp. 715-738), were used here.

The first steps in reducing the data included obtaining a J value, establishing a time line, taking a base line value or the average of two for each peak (most peaks had two base line values) and subtracting the base line value from the peak value. The peaks include the 40, 39, 37, and 36 values for argon. A linear regression was then used to obtain a correlation coefficient and an intercept for each peak value. The intercept was then multiplied by 5500 to obtain the peak height for each isotope. The intercept was also multiplied by the scale in mv and appropriate corrections were made, thus obtaining the signal in mv. The next step was to find the correction factor for the ^{37}Ar isotope to the nearest tenth of a day using the equation $C = \frac{\lambda t e^{\lambda t}}{(1 - e^{-\lambda t})}$ in an HP-25 calculator. Then, previous values were corrected for the number of days since irradiation and new values were recorded. After obtaining ratios of the isotopes, F and the ages were calculated. A computer readout was then obtained. I am using the values obtained from the computer as the final values. Using values from the computer, isochron and age spectrum diagrams were plotted. The error for each isotopic ratio was then obtained by use of predetermined % errors for the mv signals. By use of these errors, the isochron diagram was corrected by least squares fitting. A linear regression was then carried out for each sample using the x and y values for the isochron. The first R/S (using HP-25) was the intercept, the second was the slope or F, and the third was the correlation coefficient. Using F and the equation $\frac{1}{\lambda} \ln [J(F) + 1]$ with $\frac{1}{\lambda} = 1804$ m.y., the age was then calculated. The linear regressions were done with and without fusion fractions. The final calculation was the determination of the weight average plateau for the MD # 41B WR sample using the last 4 temperature fractions. This was done because of the plateau that was obtained when the age spectrum diagram was plotted.

Paleomagnetic Results and Comparisons

The paleomagnetism of the Medford diabase dike has been calculated by use of 34 samples from one site. The polarity is both normal and reversed, although my particular samples have reversed. The pole position obtained was 47°N latitude, 62°E longitude (T. E. Smith, 1976 after Corrigan, 1972). Later reliable results from 5 of 11 sites in eastern Massachusetts have yielded a mean pole position of 50.6°N latitude, 96.1°E longitude (T. E. Smith).

The values obtained prove to be very interesting when compared with pole positions for the Permian and Triassic ages. Previously determined pole positions for the Permian age in North America range from 33-52°N latitude, 103-133°E longitude while those for the Triassic age range from 48-86°N latitude, 86-121°E longitude (McElhinny, 1973). Even though the Medford diabase is considered Triassic in age, the pole positions seem to indicate otherwise. The Triassic positions are further N and E with the majority of positions noted. On the other hand, Permian latitudes are very close while longitudes are off. Therefore, Permian values appear to be best. Further values will be needed in order to clear this up in the future.

Petrographic Analysis

Introduction

Two thin sections were made for each of the Medford diabase samples. These samples, once again were numbered 40B, 41B, 45, and 47. The run for sample #40B was unsuccessful, so an analysis concerning this sample was not carried out. The results of the analyses of the remaining three are to follow.

Sample #41B   Rock Name Medford diabase
John M. McKinley

Hand Speciman Description

This core was a fine- to medium-grained green to gray-green Medford diabase apparently containing ≤1% of anhedral zeolites which occurred as xenoliths. The rest of the sample was to fine-grained to enable individual constituent identification. However, I would expect >30% of anhedral to subhedral plagioclase feldspar, 15-30% anhedral to subhedral pyroxene and/or hornblende, ≤10% anhedral chlorite (probable alteration product), 10% or less anhedral to subhedral opaques (largely magnetite), various alteration products (including sericite), and traces of various other minerals. Quartz, biotite, and potassium feldspars are not expected.

Thin Section Study

1% Zeolites: Zeolites occur in aggregates of fibrous to needlelike anhedral to subhedral grains with the aggregates ranging from .65-2mm in size. There also appears to be a large mass of sericite (or talc?) in the centers (or nearly so) of these aggregates.

5% Opaques: The opaques occurred in anhedral to subhedral grains with the majority being magnetite. The magnetite grains occurred in sizes from ≤.1 mm as well as possible somewhat magnetic grains of ilmenite and titanomagnetite. Pyrite occurred in aggregates of very small grains, with the aggregates ≤ .5 mm in size. The pyrite may also have been slightly magnetic.

20% Augite: Augite occurred in anhedral to subhedral grains ranging in size from .15-1mm with the majority from .15-.75 mm. Many of the augites were unaltered but some of the grains had altered. Apparent alteration products of pyroxene include sericite, chlorite, talc, and epidote.

65% Plagioclase: Plagioclase, of the approximate composition An_{42}, occurred in subhedral grains ranging in size from .1mm-.5 mm. The plagioclase had both albite and carlsbad twins and many were unaltered. The plagioclase that did undergo alteration usually altered to clay minerals or sericite.

8% Talc, Sericite, and Clay Minerals: These minerals occurred as alteration products in minute anhedral grains. The talc and sericite appeared to contribute to augite alteration, while sericite and clay minerals contributed to plagioclase alteration. Sericite or talc also appeared as alteration products of zeolites.

1% Chlorite and Epidote: These two minerals occurred as anhedral to subhedral grains ranging in size from .05-.10 mm and appeared to be alteration products of pyroxene.

Traces of Sphene and Hypersthene also occurred in this sample. Sphene occurred in subhedral to euhedral grains $\leq$.55 mm in size. Hypersthene occurred in subhedral grains $\lesssim$.45 mm in size.

Summary of Thin Section

Plagioclase was found in subhedral grains ranging in size from .1-.5 mm and proved to be approximately An_{42} in composition. There were many unaltered as well as altered grains. Augite occurred in anhedral to subhedral grains ranging in size from .15-1 mm. Many grains were unaltered as well as altered. Talc, sericite, and clay minerals all occurred as minute anhedral grains and were alteration products. Sericite and clay minerals were alteration products of plagioclase, talc and sericite were alteration products of pyroxenes (largely augite), and sericite was an alteration product (or talc) of zeolites. Opaques were present in anhedral to subhedral grains $\leq$.5 mm in size. The major opaque proved to be magnetite. Zeolites were present in anhedral to subhedral grains ranging from .65-2 mm in size and often were altered to sericite or talc. Finally, traces of sphene and hypersthene occurred in grains $\leq$ .55 mm in size. Hypersthene grains were subhedral, while sphene was subhedral to euhedral.

Major minerals: Plagioclase and Augite

Secondary minerals: Sphene, Hypersthene, and opaques (particularly magnetite.).

Alteration products: Chlorite, Epidote, Talc, Sericite, and Clay Minerals.

Sample #45 Rock Name: Medford diabase
John M. McKinley

Hand Speciman Description

This core was a fine-grained green to gray-green Medford diabase. Unfortunately, the sample was too fine-grained to enable individual constituent identification. However, I would expect >30% of anhedral to subhedral plagioclase feldspars, 15-30% anhedral to subhedral pyroxene and/or hornblende, 10% or less of anhedral to subhedral opaques (particularly magnetite), ≤ 10% anhedral chlorite, various alteration products, and traces (or a small %) of various other minerals. Quartz, potassium feldspars, and biotite are not expected. Biotite may occur as an alteration product of pyroxene or hornblende however.

Thin Section Study

8% Opaques: The opaques, the majority of which is magnetite, occur in subhedral to anhedral grains ranging in size from .05 mm- 1 mm. The predominant sizes range from .6 mm- .9 mm. Pyrite occurring in anhedral to subhedral grains <1 mm in size makes up approximately 1% of the total opaques. Other possible opaques include ilmenite, titanomagnetite (possibly magnetic), and pyrrhotite (possibly magnetic).

4% Chlorite: Chlorite occurs in anhedral to subhedral grains ranging in size from .1 mm-.85 mm with most in the central range. The chlorite was not particularly associated with anything. Therefore, it is probably an alteration product from either pyroxenes, biotite, or hornblende and possibly a secondary product also. I don't really see any biotite or hornblende in the sections.

1% Calcite: Calcite occurs in anhedral to subhedral grains ≤ .6 mm in size. It is associated with magnetite and plagioclase. The greatest amount of the calcite is probably an alteration product of pyroxene or plagioclase.

5% Quartz: Quartz occurs in anhedral to subhedral grains ≤.65 mm in size. The quartz is only secondary and has undulating extinction, thus it is somewhat stressed.

18% Augite: Augite occurs in anhedral to subhedral grains 1.05 mm or less in size. There is very little alteration associated with these grains. However, the chlorite leads one to believe that augite is probably replaced by it.

64% Plagioclase: Plagioclase occurs in anhedral to subhedral grains ranging from .25 mm-1.25 mm in size, maybe less. Unfortunely, these grains are extensively altered. Vestiges of albite, and possibly carlsbad, twins are present, but there are no grains in good enough shape to determine composition.

According to my result in sample #41B and some reading (Corrigan, 1972), I am led to believe that the composition ranges from An_{40}-An_{50}.

Clay minerals and sericite are present as alteration products of plagioclase. Due to the fact that every feldspar is altered, I will not give a percentage for these minerals. The anhedral grains are minute in size.

Thin Section Summary

Speciman #45 is extensively altered, particularly in regard to plagioclase. Plagioclase is present in anhedral to subhedral grains ranging up to 1.25 mm in size, but is extensively altered. The exact composition was indeterminate. Augite occurs in anhedral to subhedral grains 1.05 mm or less in size. The grains that are present are relatively unaltered, but the chlorite found in the sample may have replaced some of the augite. Opaques, particularly magnetite, are present in anhedral to subhedral grains ranging in size from .05 mm-1mm with the major sizes ranging from .6-.9 mm. Quartz occurs as a secondary mineral with anhedral to subhedral grains $\leq$.65 mm in size. All of the grains have been stressed as demonstrated by undulating extinction. Chlorite occurs as a probable secondary mineral, as well as an alteration product. It occurs in anhedral to subhedral grains ranging from .1 mm-.85 mm in size. Calcite occurs as a secondary mineral, and probably an alteration product. It is associated with magnetite and plagioclase and plagioclase and occurs in anhedral to subhedral grains $\leq$.6 mm in size. Finally, clay minerals and sericite occur in minute anhedral to subhedral grains. They are alteration products of plagioclase.

Major minerals: Plagioclase and Augite.

Secondary minerals: Chlorite (?), Quartz, Calcite (?), and opaques.

Alteration products: Clay minerals, sericite, chlorite, and calcite.

Sample #47 Rock Name Medford diabase
John M. McKinley

Hand Speciman Description

This core was a fine-grained green to gray-green Medford diabase. Unfortunately, the sample was too fine-grained to enable individual constituent identification. However, I would expect >30% of anhedral to subhedral plagioclase feldspars, 15-30% anhedral to subhedral pyroxene and/or hornblende, $\leq$10% anhedral to subhedral chlorite, 10% or less of anhedral to subhedral opaques (particularly magnetite), various alteration products, and trace (or a small %) of various secondary minerals. Biotite may occur as an alteration product of pyroxene or hornblende, while quartz may also occur if sample #45's results are any indication. Potassium feldspars are not really expected.

Thin Section Study

10% opaques: Opaques occur in grains ranging in size from .05 mm- .65 mm. Pyrite occurs in subhedral to euhedral grains ranging in size from .05mm- .50 mm with most ≤ .30 mm in size. Approximately 1% of the opaques is pyrite. The remaining opaques are largely magnetite which occurs in anhedral to subhedral grains ranging in size from .05 mm- .65 mm with most .10- .60 mm. Other possible opaques include pyrrhotite and ilmenite which may be magnetic.

5% Chlorite: Chlorite occurs in anhedral to subhedral grains ranging in size from .20 mm- 1.0 mm with most ≲ .75 mm. It is closely associated with pryoxenes and epidote which signifies that it is probably an alteration product.

1 % Quartz: Quartz occurred in anhedral to subhedral grains usually less than 1 mm in size. Most of the grains were from .40- .90 mm in size and had undulatory extinction. Therefore, the quartz was stressed.

20% Augite: Augite occurs in subhedral to anhedral grains ranging in size from .05 mm- 1.0 mm with the majority ranging from .20 mm- .90 mm. There is some alteration, but most grains are relatively unaltered. It appears that chlorite is the major alteration product.

64% Plagioclase: Plagioclase occurs in subhedral to anhedral grains ranging in size from .10 mm- .80 mm. The largest grains are relatively unaltered and exhibit Carlsbad twinning or none at all. Carlsbad and albite twins are both found, but some grains are not twinned at all. The plagioclase is extensively altered, but not as seriously as was sample #45. The alteration products include sericite, clay minerals, and calcite. The approximate composition of the feldspar is An_{47} .

Clay minerals and sericite are not given a per cent, because it is included in the plagioclase percentage. This is because the minute anhedral to subhedral grains of both are largely the result of plagioclase alteration.

Traces of Epidote and Calcite also occur. Epidote occurs in anhedral to subhedral grains ranging in size from .15 mm- .50 mm and is closely associated with chlorite and pyroxene. It is a probable alteration product of the pyroxene. Calcite occurs in anhedral to subhedral grains ≤ .10 mm in size and is associated with feldspar and magnetite. It is a probable alteration product and vein mineral of plagioclase.

Thin Section Summary

Speciman #47 is extensively altered, not as seriously as #45 though, especially in regard to plagioclase. Plagioclase is present in anhedral to subhedral grains ranging in size from .10 mm- .80 mm. There is both Carlsbad and albite twinning, but some plagioclase isn't twinned at all. The approximate composition is An_{47}. Augite occurs in anhedral to subhedral grains ranging from .05 mm- 1.0 mm in size. Chlorite and epidote are closely associated with the augite, therefore signifying some alteration even though many grains are relatively unaltered. Opaques are represented largely by magnetite and pyrite, with magnetite the most abundant. Magnetite occurs in anhedral to subhedral grains ranging in size from .05mm- .65 mm with most grains .10- .60 mm in size, while pyrite occurs in subhedral to euhedral grains ranging from .05 mm- .50 mm in size. Quartz occurs as a secondary mineral in stressed anhedral to subhedral grains ranging from .40 mm- .90 mm. Chlorite occurs in anhedral to subhedral grains ranging in size from .20 mm- 1.0 mm. The chlorite, for the most part, is an alteration product of pyroxene. Clay minerals and sericite occur as minute anhedral to subhedral grains that have resulted from plagioclase alteration. Finally, epidote and calcite occur in trace amounts. Epidote is closely associated with pyroxene and chlorite, occurring in anhedral to subhedral grains ranging in size from .15 mm- .50 mm. It is a probable alteration product of the pyroxene. Calcite occurs in anhedral to subhedral grains $\leq$.1 mm in size and is usually associated with plagioclase and magnetite. It is both a secondary mineral and a probable alteration product of plagioclase.

Major minerals: Plagioclase and Augite.

Secondary minerals: Calcite, Quartz, Epidote (?), and Opaques.

Alteration products: Chlorite, Epidote, Calcite, Clay minerals, and sericite.

Results and Conclusions

Of the specimens used for this project, only 40B was unsuccessful. The other three cores have yielded surprising results, but only 41B is the best. A summary of the results for # 45, 47, and 41B follow. Figures 2-4 and tables 1-9 also summarize the results. Table 10 is a summary of North American paleomagnetic pole positions for the Permian and Triassic ages.

Speciman #45 yielded an age spectrum and isochron diagram that seems to indicate excess Ar with some loss at low temperature. This is particularly obvious in the age spectrum diagram. Using the post-1977 constants, ages range from 228.8 m.y. for the 1075°C fraction to 257.6 m.y. in the fuse fraction. Using a linear regression, the best ages turn out to be 247.0 m.y. if all fractions are used and 231.5 m.y. if the fuse fraction isn't used. Therefore, according to this run, the Medford is Upper Paleozoic, perhaps Permian in age!

Speciman #47 yielded the same sort of results that 45 did. However, using the new constants, the age ranges from 247.8 m.y. in the 1075°C fraction to 312.9 m.y. in the fuse fraction. The excess Ar with some loss at low temperature gives an age of at least 245 m.y.. Using the linear regression, the age with all fractions ends up being 252.6 m.y. and the age without the fuse fraction ends up being 242.2 m.y.. This age is also Permian! In the case of sample 47, the result which doesn't include the fuse fraction proves to be best (as shown in the isochron and age spectrum diagrams).

The final speciman, #41B, yields an isochron and age spectrum diagram much different than the previous two. Both turn out well, all points fitting onto the isochron after least squares fitting and with the age spectrum diagram having a plateau. This plateau consists of the last four fractions. The weight average plateau turns out to be 239.1 m.y.. Age ranges from 215.2 m.y. (in the lowest fraction which isn't part of the plateau) to 242.993 m.y. in the middle fraction (950°C). The last four fractions yield ages ranging from 232.998 m.y. to 242.993 m.y.. These extremes are very similar by both hand and computer calculations, if not the same. The linear regression for this speciman yields an age of 237.6 m.y. with the fuse fraction (which is best in this case) and 241.2 m.y. without the fuse fraction. Either way, a Permian age has been yielded!

The paleomagnetic data obtained for the Medford dike coincides well with previously determined North American Permian pole positions (see table 10) with the exception of longitude. This inclines one to wonder about the previously determined

Triassic age for the dike. Triassic pole positions do not coincide very well (at least for the majority).

In conclusion, this project has shed new light upon the age and intrusion of the dike. It yields a possible Permian age for the Central Atlantic rift and adds to the accuracy of the paleomagnetic reconstruction of continents. It also provides further information for determining the relationship of the dike to its surrounding geology. The three sample runs, as well as the paleomagnetic data, all support the Permian age. This causes considerable fervor as to the Medford dike's age, but still does not prove that the Triassic age is incorrect. Therefore, more research and dating of the dike will be necessary in the future. I have no doubt that this will occur. I enjoyed doing this project and would like to keep track of further developments (if I don't participate in them) concerning the dike.

OSU - MICH #3

TEMP (°C)	$^{40}Ar/^{39}Ar$ (measured)	$^{37}Ar/^{39}Ar$ (corrected)	$^{36}Ar/^{39}Ar$ (measured)	$^{40}Ar_R/^{39}Ar_K$ (F)	^{39}Ar (% of total)	Age in m.y. Pre 1977 const	Post 1977 const
SAMPLE: MD #45 WR		J(old): 0.009197			J(new): 0.009874		
600°C	21.743	1.194	0.026287	14.080	2.38	229.539 ± 14.840	234.835 ± 15.118
800°C	16.123	0.720	0.005617	14.524	16.77	236.341 ± 3.164	241.766 ± 3.223
950°C	16.701	0.600	0.009026	14.084	6.01	229.604 ± 5.758	234.902 ± 5.867
1075°C	14.984	0.507	0.004523	13.689	26.39	223.519 ± 2.895	228.703 ± 2.950
FUSE	16.775	4.436	0.005537	15.551	48.46	251.976 ± 2.887	257.688 ± 2.939
TOTAL GAS	16.307	2.469	0.005986	14.763	100%	239.992	245.486

Table 1: Data used in determination of age for MD #45 WR sample. Ages are also given (Computer data, not data from hand calculations).

600°C 9/27/79 A

	40	39	37	36	
Scale	1V	30mv	10mv	10mv	
PK. HT.	1810	2734	(804) 9666	211	t' = 123.8
mv.	329.13	15.134	(1.5038) 18.08	0.39727	

800°C 9/27/79 B

Scale	3V	300mv	30mv	10mv	
PK. HT.	3155	1940	(1133) 13648	318	t' = 123.9
mv.	1721.34	106.75	(6.3754) 76.80	0.60040	

950°C 9/27/79 C

Scale	1V	100mv	10mv	10mv	
PK. HT.	3512	2083	(1019) 12274	183	t' = 123.9
mv.	638.67	38.241	(1.9060) 22.96	0.34450	

1075°C 9/27/79 D

Scale	10V	300mv	30mv	10mv	
PK. HT.	1378	3053	(1254) 15135	403	t' = 124.0
mv.	2518.33	168.02	(7.0598) 85.21	0.75972	

Fuse 9/27/79 E

Scale	10V	1V	300mv	10 mv	
PK. HT.	2833	1683	(2021) 24465	906	t' = 124.1
mv.	5175.80	308.62	(113.08) 1367	1.7080	

TOTAL GAS

Scale				
PK. HT.				
mv.	10383.27	636.765	1570.05	3.80989

Table 2: Preliminary calculations for dating based on chart reduction. t' is the correction factor for ^{37}Ar and values in parentheses are uncorrected (MD #45 WR sample of OSU-MICH #3)

	(Y) $^{40}Ar_{R+A}/^{36}Ar_A$	vs.	(X) $^{39}Ar_K/^{36}Ar_A$
600°C	838 ± 50		38.5 ± 2.0
800°C	2,970 ± 164		185 ± 10
950°C	1886 ± 170		113 ± 10
1075°C	3421 ± 171		228 ± 11
Fuse	3910 ± 108		232 ± 6.5

1st R/S	Intercept	238.6 (all)	321.1 (w/o fuse)
2nd R/S	Slope (F)	14.86 (all)	13.87 (w/o fuse)
3rd R/S	Correlation Coeff.	.9846 (all)	.9972 (w/o fuse)

$$t_u = \frac{1}{\lambda} \ln \left[J(F) + 1 \right]$$

$$\frac{1}{\lambda} = 1804 \text{ m.y (new)}$$

Age (all): 247.0 m.y.
Age (w/o fuse): 231.5 m.y.

Table 3: Isochron data and values obtained as a result of the linear regression of y-x values for MD #45 WR sample of OSU-MICH #3.

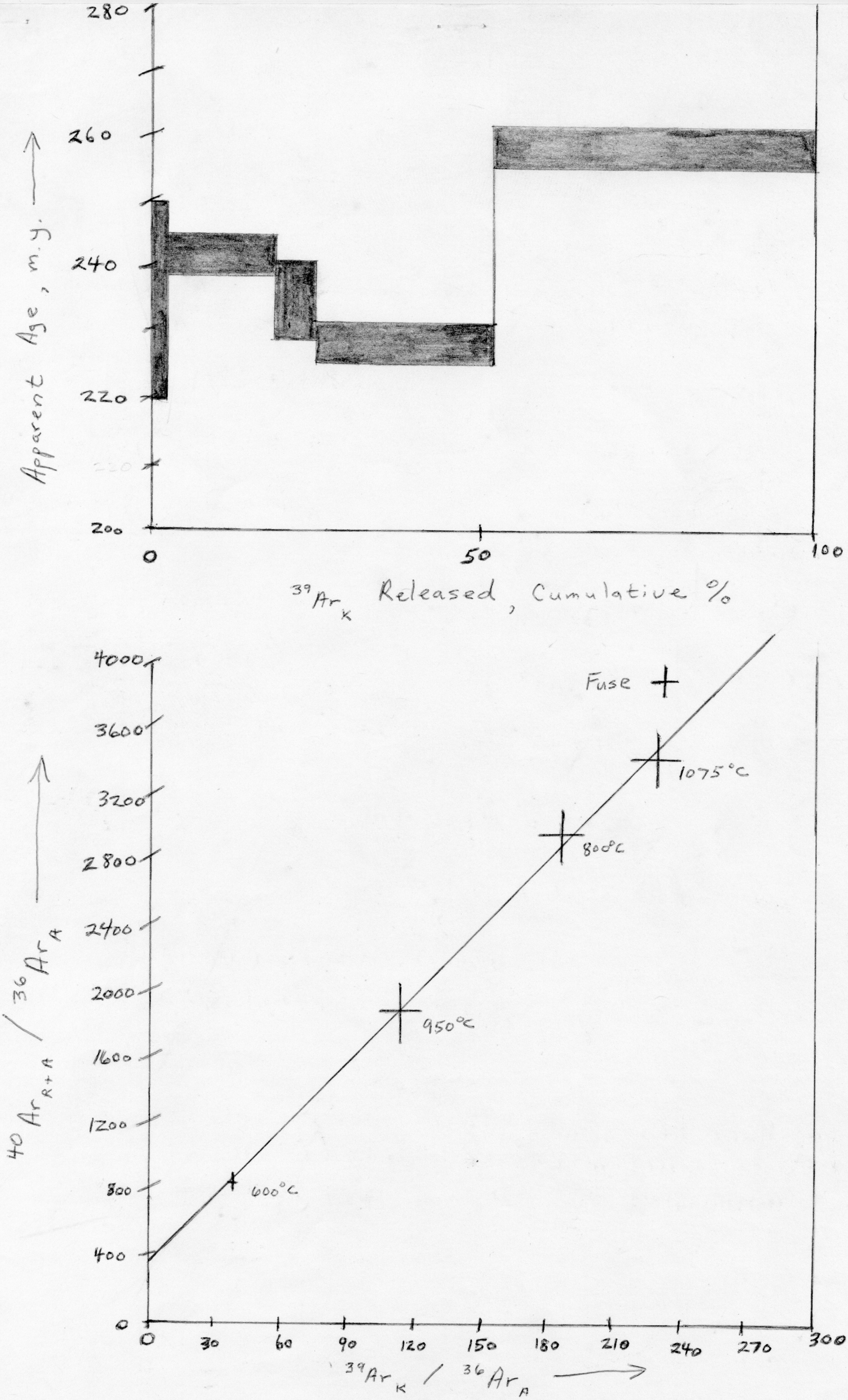


Fig. 2: Age spectrum and isochron diagram for MD #45 WR sample.

OSU - MICH #3

TEMP (°C)	$^{40}Ar/^{39}Ar$ (measured)	$^{37}Ar/^{39}Ar$ (corrected)	$^{36}Ar/^{39}Ar$ (measured)	$^{40}Ar_R/^{39}Ar_K$ (F)	^{39}Ar (% of tot.)	Age in m.y. Pre 1977 const	Post 1977 const
SAMPLE :	MD #47WR		J(old) : 0.009197			J(new) :	0.009874
600°	33.563	2.616	0.057113	16.930	3.37	272.771 ± 16.410	278.853 ± 16.693
800°	22.919	2.150	0.021202	16.853	10.63	271.621 ± 6.809	277.683 ± 6.927
950°	22.824	1.749	0.023888	15.925	6.19	257.640 ± 7.496	263.455 ± 7.630
1075°	16.474	1.443	0.005731	14.909	39.32	242.222 ± 3.230	247.756 ± 3.289
FUSE	21.696	11.675	0.012294	19.189	40.50	306.365 ± 3.910	313.011 ± 3.974
TOTAL GAS	20.242	5.720	0.012886	16.973	100%	273.427	279.520

Table 4: Data used in determination of age for MD #47WR sample. Ages are also given. (Computer data)

600°C 9/28/79 A

	40	39	37	36
Scale	1V	30 mv	10 mv	10 mv
PK. HT.	2188	2141	(1352) 16576	359
MV.	397.84	11.851	(2.5290) 31.006	0.6774

800°C 9/28/79 B

Scale	3V	100 mv	30 mv	10 mv
PK. HT.	1573	2040	(1164) 14306	421
MV.	858.17	39.291	(7.6103) 93.531	0.7940

950°C 9/28/79 C

Scale	1V	100 mv	10 mv	10 mv
PK. HT.	2735	1187	(1658) 20377	276
MV.	497.35	21.789	(3.1014) 38.116	0.5201

1075°C 9/28/79 D

Scale	10V	300 mv	30 mv	10 mv
PK. HT.	1249	2517	(2884) 35502	421
MV.	2282.36	138.49	(16.2352) 199.86	0.7940

FUSE 9/28/79 E

Scale	10V	300 mv	300 mv	10 mv
PK. HT.	1694	2592	(2414) 29765	930
MV.	3094.40	142.66	(135.06) 1665.29	1.7529

TOTAL GAS

Scale				
PK. HT.				
MV.	7130.12	354.081	2027.80	4.5384

Table 5: Preliminary calculations for dating based on chart reduction. t' is the correction factor for ^{37}Ar and values in parentheses are uncorrected. (MD #47 WR sample of OSU-MKH #3)

	Y		X
	$^{40}Ar_{R+A}/^{36}Ar_A$	vs.	$^{39}Ar_K/^{36}Ar_A$
600°C	595 ± 33		17.7 ± 0.99
800°C	1113 ± 56		48.5 ± 2.4
950°C	975.5 ± 56		42.7 ± 2.5
1075°C	3093 ± 155		188 ± 9.5
Fuse	2407 ± 67		110 ± 3.1

1st R/S	Intercept	398.0 (all)	364.3 (w/o fuse)
2nd R/S	Slope (F)	15.22 (all)	14.55 (w/o fuse)
3rd R/S	Corr. Coef.	.9666 (all)	.9993 (w/o fuse)

$$t_u = \frac{1}{\lambda} \ln \left[J(F) + 1 \right]$$

$$\frac{1}{\lambda} = 1804 \text{ m.y. (new)}$$

Age (all) : 252.6 m.y.

Age (w/o fuse): 242.2 m.y.

Table 6: Isochron data and values obtained as a result of the linear regression of y-x values for MD #47 WR sample of OSU-MICH #3.

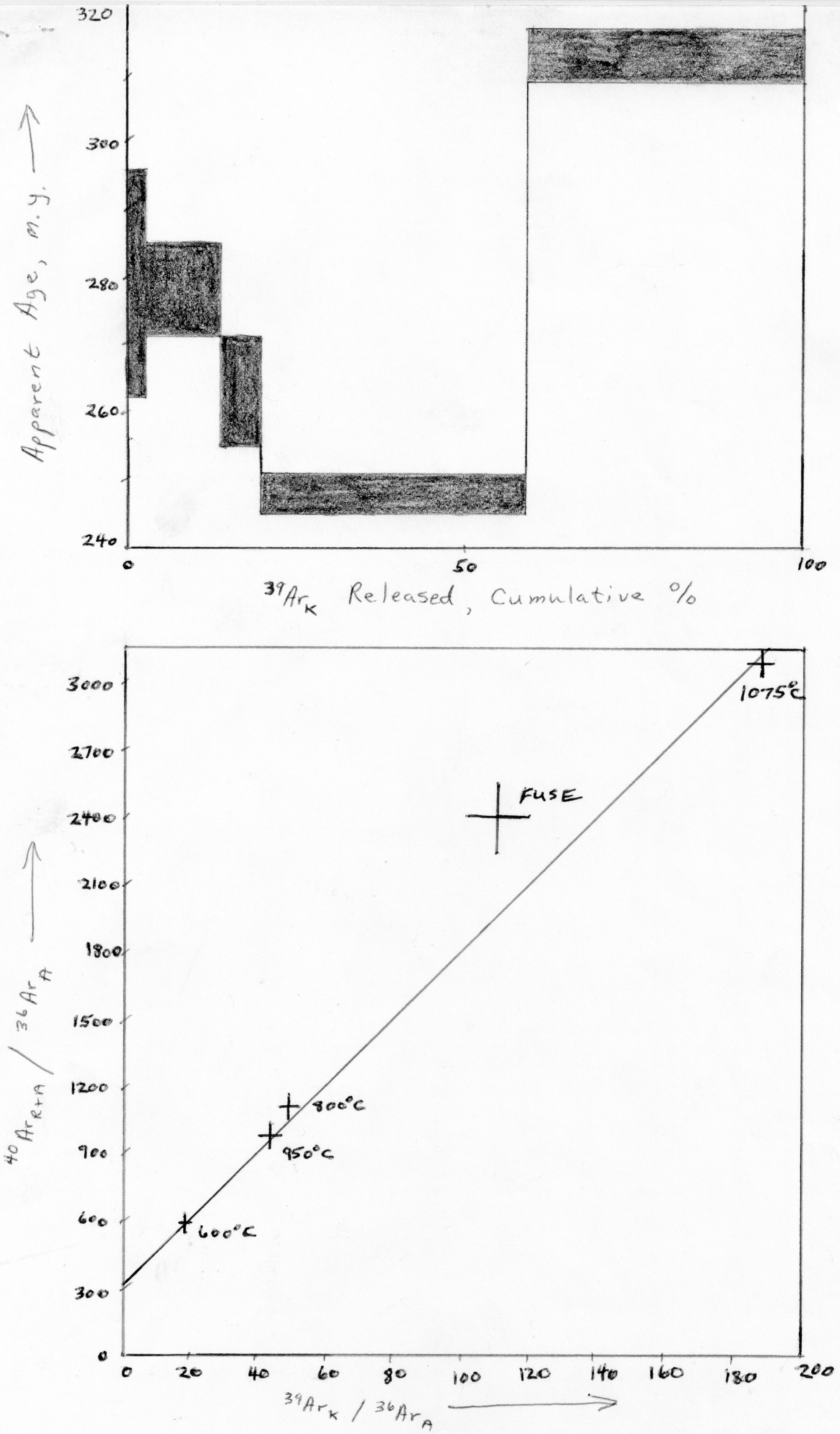


Fig. 3: Age spectrum and isochron diagram for MD #47 WR sample.

OSU-MICH #3

TEMP (°C)	$^{40}Ar/^{39}Ar$ (measured)	$^{37}Ar/^{39}Ar$ (corrected)	$^{36}Ar/^{39}Ar$ (measured)	$^{40}Ar_R/^{39}Ar_K$ (F)	^{39}Ar (% of total)	Age in m.y.	
						Pre 1977 const	Post 1977 const
SAMPLE: MD #41B WR		J(old) = 0.009197		J(new) = 0.009874			
600°	48.279	1.991	0.120555	12.833	7.26	210.302 ± 18.52	215.230 ± 18.88
800°	24.396	3.018	0.034422	14.501	22.77	235.986 ± 5.818	241.404 ± 5.926
950°	21.521	3.060	0.024359	14.603	22.17	237.546 ± 5.446	242.993 ± 5.546
1075°	18.312	2.898	0.014442	14.309	27.98	233.045 ± 4.381	238.409 ± 4.463
FUSE	18.252	14.581	0.019093	13.963	19.81	227.735 ± 5.375	232.998 ± 5.477
TOTAL GAS	22.574	5.210	0.029820	14.242	100%	232.028	237.371

Table 7: Data used in determination of age for MD #41B WR sample. Ages are also given. (Computer data, very similar to results of the hand calculations)

600°C 10/1/79 A

	40	39	37	36
Scale	3V	30mv	10mv	10mv
PK. HT.	1506	3074	(1389) 18112	1088
mv.	821.49	17.018	(2.5978) 33.875	2.0510

800°C 10/1/79 B

Scale	3V	100mv	30mv	10mv
PK. HT.	2386	2907	(2194) 28610	974
MV.	1301.75	53.364	(12.348) 161.02	1.8364

950°C 10/1/79 C

Scale	3V	100mv	30mv	10mv
PK. HT.	2049	2830	(2162) 28236	671
mv.	1117.90	51.936	(12.167) 158.90	1.2659

1075°C 10/1/79 D

Scale	3V	100mv	30mV	10mv
PK. HT.	2200	3571	(2584) 33747	502
mv.	1200.24	65.549	(14.546) 189.97	0.9474

FUSE 10/1/79 E

Scale	3V	100mV	30mv	10mV
PK. HT.	1553	2529	(2771) 36272	470
MV.	847.10	46.426	(51.708) 676.86	0.8872

TOTAL GAS

Scale				
PK. HT.				
mv.	5288.48	234.293	1220.62	6.9879

Table 8: Preliminary calculations for dating based on chart reduction. t' is the correction factor for ^{37}Ar and values in parentheses are uncorrected. (MD #41B WR sample of OSU-MICH #3).

	Y		X
	$^{40}Ar_{R+A}/^{36}Ar_A$	vs.	$^{39}Ar_K/^{36}Ar_A$
600°C	402 ± 10		8.3 ± 0.22
800°C	727 ± 18		29.7 ± 0.76
950°C	916 ± 28		42.5 ± 1.3
1075°C	1344 ± 54		73.2 ± 3.0
Fuse	1217 ± 55		66.0 ± 3.0

1st R/S	Intercept	294.8 (all)	290.5 (w/o fuse)
2nd R/S	Slope (F)	14.26 (all)	14.49 (w/o fuse)
3rd R/S	Correlation Coef.	.9986 (all)	.9994 (w/o fuse)

$$t_u = \frac{1}{\lambda} \ln\left[J(F) + 1\right]$$

$$\frac{1}{\lambda} = 1804 \text{ m.y. (new)}$$

Age (all): 237.6 m.y.

Age (w/o fuse): 241.2 m.y.

wt. average plateau age: 239.1 m.y.

Table 9: Isochron data and values obtained as a result of the linear regression of y-x values for MD #41B WR sample of OSU-MICH #3.

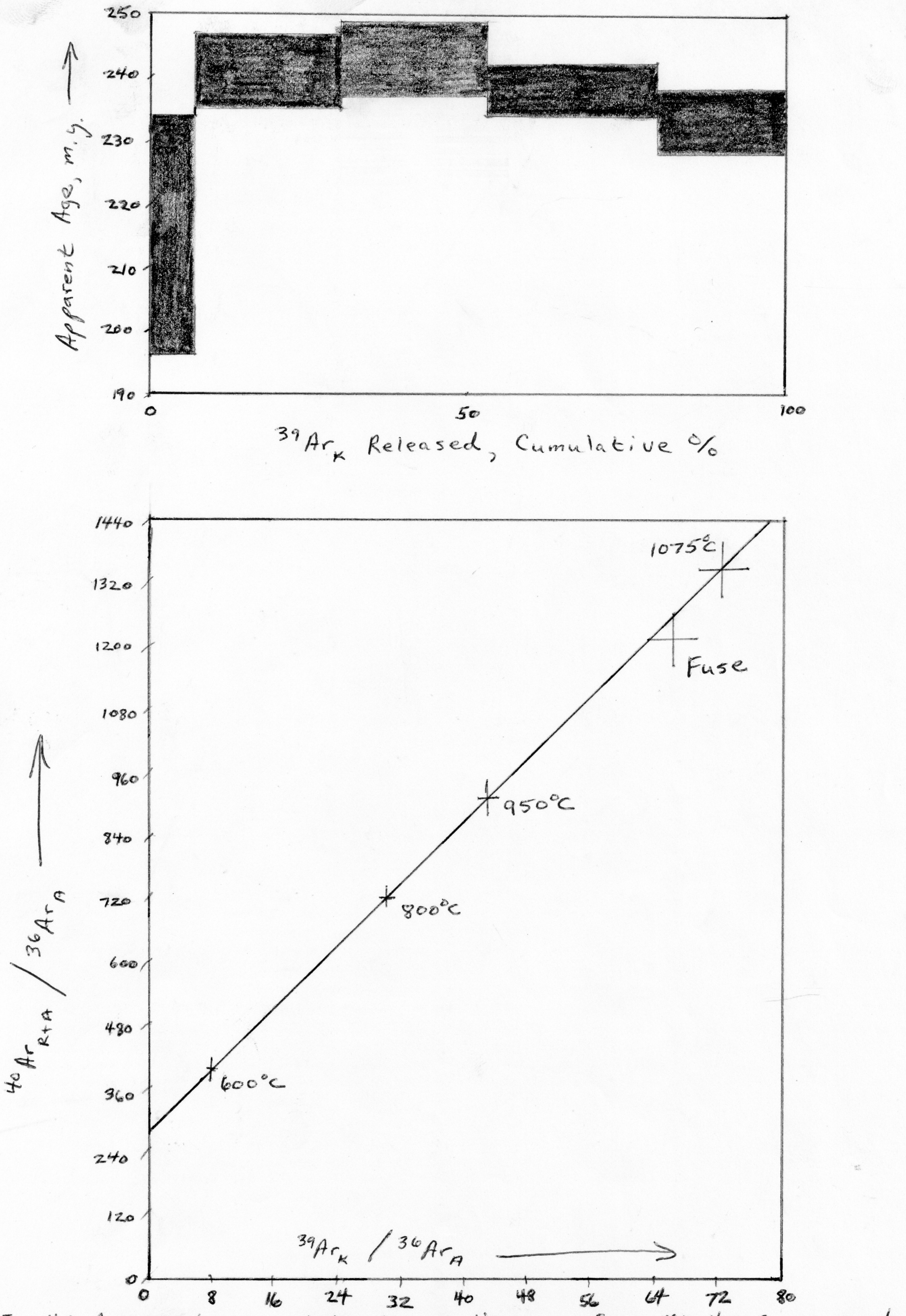


Fig. 4: Age spectrum and isochron diagram for MD #41B WR sample.

	Pole position	Age (my)	Samp./Sites	Pol.
Medford diabase	47°N, 62°E	P/Tr (?)	34/1	Mixed (Tim Smith, 1976)
Medford diabase	50.6°N, 96.1°E	P/Tr (?)	5 of 11 sites	Mixed (Tim Smith abstract)
	40°N, 126°E	Pn(u) - Pl	154/3	Reversed
	42°N, 133°E	Pn(u) - Pl	58/17	Reversed
	38°N, 133°E	Pn(u) - Pl	21/11	Reversed
	44°N, 122°E	Pl	57/9	Mixed
	33°N, 126°E	Pn(u) - Pl	36(-)	Reversed
*	48°N, 119°E	Pn(u) - Pl	27(-)	Reversed
*	52°N, 113°E	Pu	12	Reversed
*	47°N, 103°E	P	11	Reversed
*	49°N, 117°E	P	14	Reversed
	57°N, 107°E	Trl	92/8	Mixed
	48°N, 112°E	Trl	98/10	Mixed
	60°N, 88°E	Trl (225)	44/11	Normal
	57°N, 89°E	Trl (225)	6 (-)	Normal
	58°N, 117°E	Trl	163	Mixed
	56°N, 100°E	Trl	11 (-)	Mixed
	50°N, 121°E	Trl	18	Reversed
	57°N, 89°E	Trl	318/12	Mixed
	54°N, 86°E	Tru	12	Mixed
	63°N, 108°E	Tru (190)	78/29	Normal
	55°N, 88°E	Tru	16/5	Normal
	69°N, 98°E	Tru (197)	11/2	Normal
	62°N, 105°E	Tru	95/20	Normal
	66°N, 113°E	Tru (200)	28/17	Normal
	68°N, 91°E	Tru	387/50	Mixed
	65°N, 87°E	Tru (193)	313/7	Normal
	73°N, 104°E	Tru (200)	40/25	Normal
	80°N, 100°E	Tru	8/4	Normal
	86°N, 118°E	Tru (202)	73/10	Reversed

Table 10: Paleomagnetic data and results; all but the first two datum after McElhinny, 1973.

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